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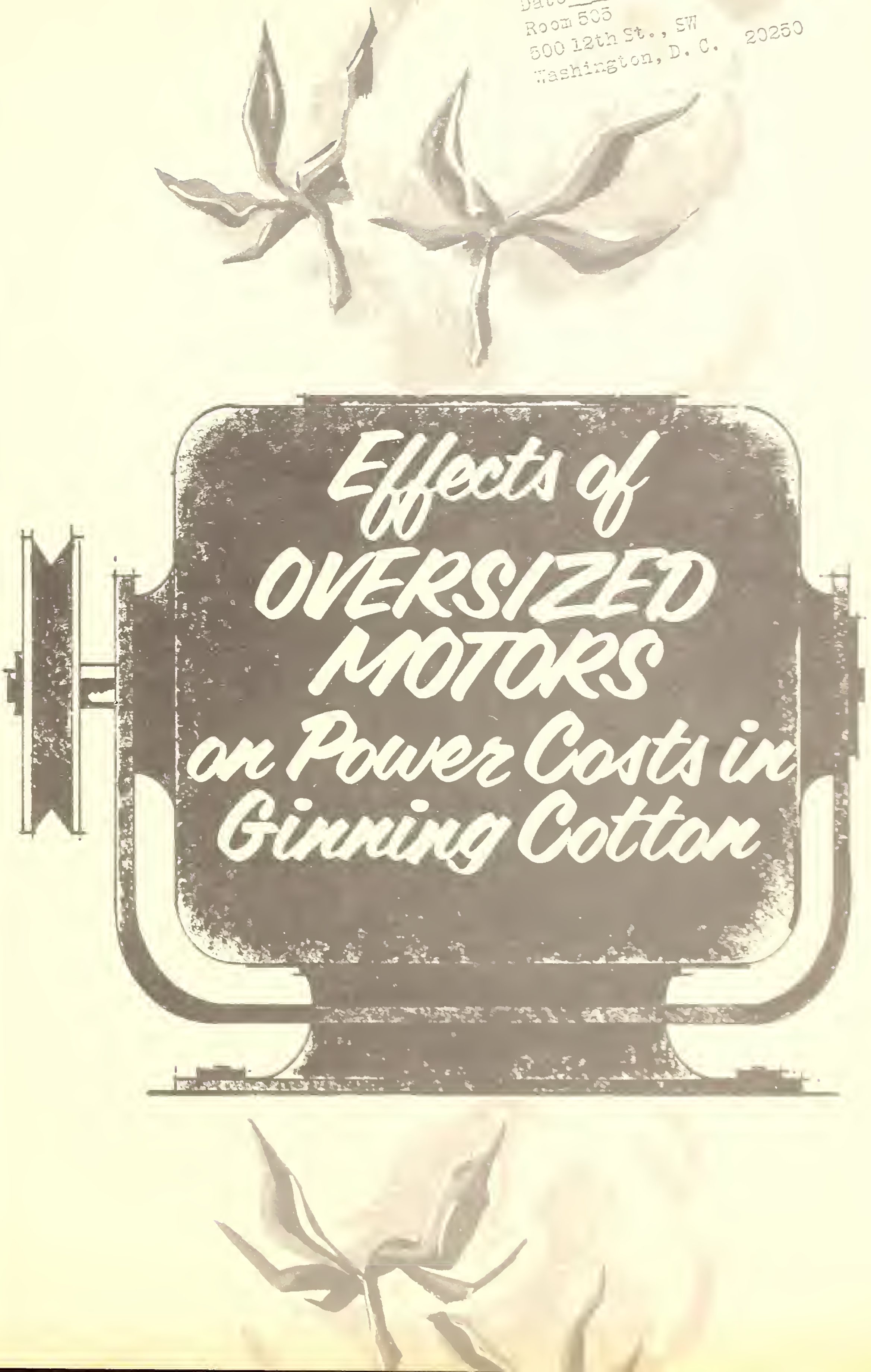

Effects of OVERSIZED MOTORS on Power Costs in Ginning Cotton

There are 3 basic means of attaining more desirable power factor levels. They are: (1) Properly sizing motors to the jobs to be performed--during the initial installation, preferably, or later by advancing motors to heavier jobs and replacing the smallest with others even smaller to secure optimum performance; (2) adding corrective devices to motors already installed--either to further improve the existing power factor level in an already properly sized motor complement or as an alternative in raising a lower power factor level without first correcting the motor size; and (3) some combination of the two.

The advisability of establishing and maintaining higher power factors in cotton gins, from an economic standpoint, depends mainly upon the costs involved and the benefits derived. It is of particular importance to strive for the highest power factor attainable without corrective devices during an initial power installation, and then to add capacitance to raise the power factor to the desired level. A power factor level of at least 0.95 appears to be both feasible and desirable with induction motors.

EFFECTS OF OVERSIZED MOTORS ON POWER COSTS IN GINNING COTTON

by

Charles A. Wilmot and David M. Alberson 1/

INTRODUCTION

During the past two decades the cotton ginning industry has made an almost complete transition from the predominant use of internal combustion engines, with line and jack-shafts, to all-electric, individually motored ginning equipment. This development, while adding substantially to the flexibility of plant operation, has been accompanied by a gradual but continuous increase in connected horsepower per gin. For example, during the 1945-46 ginning season the average total connected horsepower for gins in New Mexico was 140, for West Texas 159, and for California 185. In 1962, total connected horsepower for gins in these same three areas averaged 392, 646, and 677, respectively.2/ Today, many new gin plants are being erected with total connected loads in excess of 1,200 horsepower.

The Problem

While modern gins are much faster than their counterparts of 10 to 20 years ago, increases in sustained ginning rate capabilities have not kept pace with increases in total connected horsepower. This has resulted in power accounting for a continually increasing proportion of the total operating costs.

Increases in total connected horsepower have been due mainly to two factors. First, the evolution from hand to mechanical harvesting during the past decade has necessitated the development and use of additional processing equipment to maintain high-quality ginning. Second, the trend to all-electric gins has been accompanied by a tendency to overmotor which implies the use of oversized motors or horsepower in excess of that necessary to operate the equipment.3/

Little can be done about additional equipment required to properly prepare and gin the more roughly harvested seed cotton which gins are now called upon to handle. However, the use of oversized electric motors resulting in higher costs for power can be corrected. Efficiency curves developed for electric motors show that peak performance is attained at approximately full load. In comparison, internal combustion engines normally should be operated somewhere between 70 and 90 percent of full load for maximum efficiency. Therefore, for most efficient power usage, the connected horsepower in an all-electric gin

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1/ Agricultural Economist, Economic Research Service; and Agricultural Engineer, Agricultural Research Service, respectively.

2/ Wilmot, Charles A. and Alberson, David M. Increasing the Efficiency of Power Used for Materials Handling in Southwestern Cotton Gins, ERS 154, U.S. Dept. Agr., March 1964, p. 5.

3/ Three terms--"overmotoring," "underloading," and "excess of surplus connected horsepower"--are used interchangeably throughout this report.

should be substantially less than in an identical gin powered by an internal combustion engine.[4]

Unfortunately, this important difference in performance between electric motors and internal combustion engines is apparently disregarded or overlooked. As a result, overmotoring in present-day all-electric gin plants is, needlessly, in about the same proportion as the gins powered by internal combustion engines.

Purpose and Objectives

A study of southwestern cotton gins during the 1961-62 season revealed that there were wide variations but general excesses in total connected loads among gins.[5] The average operating load ranged from 77 to 85 percent of average connected load among the three specific areas studied. Likewise, in a 1962-63 study of gins in Mississippi, average operating load was found to be approximately 80 percent of average connected load.[6]

Since unused capacity in electric motors means unnecessarily high initial costs and continually higher operating costs, the present study was initiated to: (1) Determine the extent of, reasons for, and effects of overmotoring in cotton gins; (2) ascertain the interrelationships between overmotoring and power costs; (3) develop a simplified means by which individual ginners can measure actual power requirements and determine power factors; and (4) determine the means and advisability of correcting overmotoring and low power factors in cotton gins, and the economic benefits to be derived.

Sources of Data

Information relating to the general extent of overmotoring in electric-powered gins was derived from data collected from 18 plants in the southwest and the far-west producing areas. Data for California, New Mexico, and West Texas gins were obtained during the 1961-62 ginning season and for Arizona gins during the 1963-64 season. Gins were selected to assure equitable representation both by geographic area and by gin size. Gin size was determined on the basis of maximum hourly ginning rate, as follows: Small--up to 8 bales; medium--8 to 12 bales; and large--12 bales and over.[7] Two gins in each size group, or a total of 6, were selected from each of the following 3 producing areas: The San Joaquin Valley of California, the Arizona-New Mexico desert area, and the Texas High Plains.

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[4] This is assuming that about 80 percent of capacity has been determined as the most efficient operating load for a particular internal combustion engine of the type used in cotton gins. If a total of 640 horsepower was actually required to operate the gin plant, then an engine rated at approximately 800 horsepower would be necessary. However, with individual electric motors a total of only 640 horsepower would be necessary, making a difference of approximately 160 horsepower between the 2 gins. Note--electric motors, of the type employed in cotton gins, generally have a built-in "safety margin" known as a service factor which permits temporary overloading up to a designated level, usually 115 to 120 percent.

[5] Wilmot, Charles A., and Alberson, David M. Increasing the Efficiency of Power Used for Materials Handling in Southwestern Cotton Gins, ERS 154, U.S. Dept. Agr., March 1964, p. 5.

[6] Watson, Harold, Griffin, A. Clyde, and Holder, Shelby H. Power Requirements for High-Capacity Cotton Gins in the Yazoo-Mississippi Delta, U.S. Dept. Agr., Agr. Res. Serv., ARS 42-94, Jan. 1964.

Data concerning the nature and extent of use of power factor adjustment clauses in utility contracts were obtained primarily from secondary sources.[8] Representatives of a few large utility companies were interviewed to secure rate schedule explanations and interpretations, and information regarding long range outlook and plans for changes in power company operating practices.

OVERMOTORING IN COTTON GINS

In all 18 of the sample gins, there was an excess of connected power when ginning at peak capacities as well as when running idle. In 16 of the gins, the ratio of horsepower actually required to total horsepower connected (gin load) ranged from 56 to 85 percent. This is more typical of what one would expect in gins powered with internal combustion engines rather than in electrically operated plants.

There was an excess of connected power when ginning at peak capacities as well as when running idle in all 18 sample gins. The gin load, which is the ratio of horsepower actually required to operate the gin plant to the total horsepower connected and available, for these gins was as follows:

Number of gins	Gin load (percent)
3	56-65
4	66-75
9	76-85
2	86 and over
18	

In 16 of the gins, the gin load ranged from 56 to 85 percent. This is more typical of what one would expect in gins powered with internal combustion engines rather than in electrically operated plants.

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[7] Based on saw gin standards. Three roller gins from the Arizona-New Mexico area, which were included in the sample, were classified on the basis of roller gin standards.

[8] Data obtained from National Electric Rate Book--Arizona, issued Sept. 1961; California, issued Nov. 1961; New Mexico, issued July 1961; Texas, issued June 1961. Federal Power Commission, Washington 25, D.C.

Causes

There are several reasons for the widespread prevalence of overmotoring in cotton gins. First, motors are often replaced or added with little regard to proper sizing. Surplus motors are freely substituted as "temporary" replacements, so long as they are of ample size to handle the load. "Temporary" substitutions usually become permanent, however, unless they fail to perform satisfactorily. Therefore, in a majority of older gins, a general situation of overmotoring frequently prevails.

Second, there is a lack of testing know-how in many gin plants. Although ginners usually have access to and make use of both the voltmeter and the ammeter in varying degrees, few fully understand the significance of power readings and their applications in evaluating and improving ginning operations. Such readings are virtually meaningless unless correctly analyzed and interpreted.

Third, plans for new construction or for remodeling older gin plants usually call for excess connected horsepower, even in all-electrically powered gins. The recommendation for excess power, while necessary in certain situations due to the inflexibility of motor sizes, appears in general to be a carryover from the days when gins were powered by internal combustion engines. This is not to infer that gin engineers are unaware of the difference in optimum efficiency levels between induction motors and internal combustion engines. Rather, it is presumed that they have learned to respect ginners' general disregard for proper motor sizing and have adopted a common policy of recommending overmotoring as a safeguard to overloading. Also, gin manufacturers are primarily concerned with ginning performance as related to rate of production, lint quality, and machine dependability rather than with economies of scale in gin power usage. Responsibility for correcting this persistent trend rests with both ginners and gin-design or sales engineers.

Effects

For all practical purposes, energy required by an induction motor is dependent upon the load regardless of motor size within a rather wide range. For example, a 15-horsepower induction motor operating at full load, a 20-horsepower motor operating at three-fourths load, and a 30-horsepower motor operating at one-half load all require approximately the same kilowatt inputs (table 1). However, this does not mean that these 3 motors can be used interchangeably without affecting operating costs. Operating a motor at considerably less than full load reduces both its power factor and its mechanical efficiency, thereby increasing the cost of operation.

Power factor is the ratio of useful energy to total energy inputs; it varies with motor size, speed of operation, and load. The formula for computing this ratio is:

$$\text{Power factor} = \frac{\text{Kilowatts}}{\text{Kilovolt-amperes}}$$

Table 1.--Kilowatt inputs for induction motors at different load levels, normal-torque, normal-starting current, 3-phase, 60-cycle, squirrel-cage design, 220, 440, 550 volts

Rated hp.	Full load r.p.m.	Kilowatt input		
		Full load	3/4-load	1/2-load
1	1,720	0.95	0.71	0.48
1-1/2	1,740	1.42	1.06	0.74
2	1,740	1.87	1.40	0.96
3	1,720	2.80	2.07	1.43
5	1,735	4.47	3.31	2.25
7-1/2	1,740	6.70	4.97	3.37
10	1,745	8.78	6.54	4.39
15	1,750	13.20	9.87	6.62
20	1,760	17.00	12.90	8.98
25	1,760	20.80	15.70	10.70
30	1,760	25.00	18.90	13.00
40	1,765	33.30	25.20	17.30
50	1,765	41.40	31.30	21.40
60	1,775	49.40	37.30	25.60
75	1,775	61.40	46.70	31.80
100	1,775	82.40	62.20	42.40

Source: Rogers, Price L., Power Factor Economics (New York: John Wiley and Sons, Inc., 1939), pp. 23-25.

The total energy input (kilovolt-amperes) required to operate an induction motor is not all converted to usable power output. Instead, a portion of this energy is required in the motor operation to "magnetize the fields." Therefore, the kilovolt-amperes is sometimes referred to as apparent power in contrast to the number of kilowatts which is a measure of the true or useful energy.[9]

In general, power factors improve with an increase in motor loading but at a declining rate (table 2). This relationship between power factors and motor load is confirmed by the data from the 18 sample gins which were analyzed in this study (figure 1).

In contrast with power factor losses, mechanical efficiency of induction motors varies only slightly regardless of motor load. These losses of input energy result from friction, windage, and other factors. A range in efficiency factors from 85 to 90 percent would include most induction motors within the sizes and speeds normally employed in cotton gins (table 3).

UTILITY RATE ADJUSTMENTS BASED ON POWER FACTOR

Rate schedules and service contracts representing a total of 121 utility companies covering the four-State sample gin area were analyzed to determine the interrelationship between overmotoring and power costs. Of this total, 61 utilities had incorporated clauses with their contracts which provided for refunds or penalties depending upon the power factor level maintained.[10] These clauses fell into 6 general categories or types. For this report they were classified generally into Types A-F, as follows:

Type A

Monthly energy charges will be decreased by _____ cents for each kw. of increased maximum demand and increased by _____ cents for each kvar of reactive demand.

Type B

Monthly energy charges will be reduced _____ percent for each 1 percent increase in the weighted monthly average power factor above _____ percent up to

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[9] This relationship may be expressed as follows:

$$\underset{\text{(apparent power)}}{\text{Kilovolt-amperes}} - \underset{\text{(power lost to motor)}}{\text{field magnetizing current}} = \underset{\text{(useful energy)}}{\text{kilowatts}}$$

[10] Cotton gins were not governed by contracts with power factor adjustment clauses, in all cases. In fact, in several instances special rate schedules excluding such clauses were applicable to cotton gins only. However, during conversations with key personnel, it was disclosed that long-range plans include power factor adjustments for cotton gins as soon as reactive kv.-a. meters or other permanent power factor recording equipment can be installed at each gin plant. This has been brought on by the trend to more and more connected equipment and horsepower resulting in continually climbing peak demands.

Table 2.--Power factor characteristics of induction motors at different load levels, normal-torque, normal-starting current, 3-phase, 60-cycle, squirrel-cage design, 220, 440, 550 volts

Rated hp.	Full load r.p.m.	Kilowatt input		
		Full load	3/4-load	1/2-load
		Percent	Percent	Percent
1......	1,720	80	72	61
1-1/2..	1,740	82	75	62
2......	1,740	84	78	68
3......	1,720	87	82	71
5......	1,735	88	83	75
7-1/2..	1,740	89	85	75
10.....	1,745	89	85	75
15.....	1,750	90.5	85	76
20.....	1,760	88.5	84	73
25.....	1,760	90	86.5	78
30.....	1,760	91	89	82
40.....	1,765	90	88	82
50.....	1,765	91	89	82
60.....	1,775	91	88	80
75.....	1,775	91	88	80
100....	1,775	91	88.5	80

Source: Rogers, Price L., Power Factor Economics (New York: John Wiley and Sons, Inc., 1939), pp. 23-25.

Table 3.--Mechanical efficiency characteristics of induction motors at different load levels, normal-torque, normal-starting current, 3-phase, 60-cycle, squirrel-cage design, 220, 440, 550 volts

Rated hp.	Full load r.p.m.	Kilowatt input		
		Full load	3/4-load	1/2-load
		Percent	Percent	Percent
1.......	1,720	78.5	79	77
1-1/2...	1,740	79	79	76
2.......	1,740	80	80	78
3.......	1,720	80	81	78
5.......	1,735	83.5	84.5	83
7-1/2...	1,740	83.5	84.5	83
10......	1,745	85	85.5	85
15......	1,750	85	85	84.5
20......	1,760	88	87	83
25......	1,760	89.5	89	87
30......	1,760	89.5	89	86
40......	1,765	89.5	89	86.5
50......	1,765	90	89.5	87
60......	1,775	90.5	90	87.5
75......	1,775	91	90	88
100.....	1,775	90.5	90	88

Source: Rogers, Price L., Power Factor Economics (New York: John Wiley and Sons, Inc., 1939), pp. 23-25.

and including _____ percent, and increased _____ percent for each 1 percent in the weighted monthly average power factor below _____ percent.

Type C

Utility may require maintenance of power factor to not less than _____ percent, lagging or leading.

Type D

(1) Monthly energy charge determined on basis of _____ percent maximum kv.-a. demand in lieu of kw. demand, or (2) if power factor is less than _____ percent, monthly bill will be increased $_____ for each kv.-a. of measured demand by which actual kv.-a. measured demand exceeds the kv.-a. demand at _____ percent power factor.

Type E

Charge of _____ cents for each kvar of maximum reactive demand in excess of _____ percent of maximum kw. demand.

Type F

(1) If power factor, as determined during period of maximum demand, is less than _____ percent, billing demand will be adjusted by multiplying maximum measured kw. demand by _____ percent and dividing by actual power factor

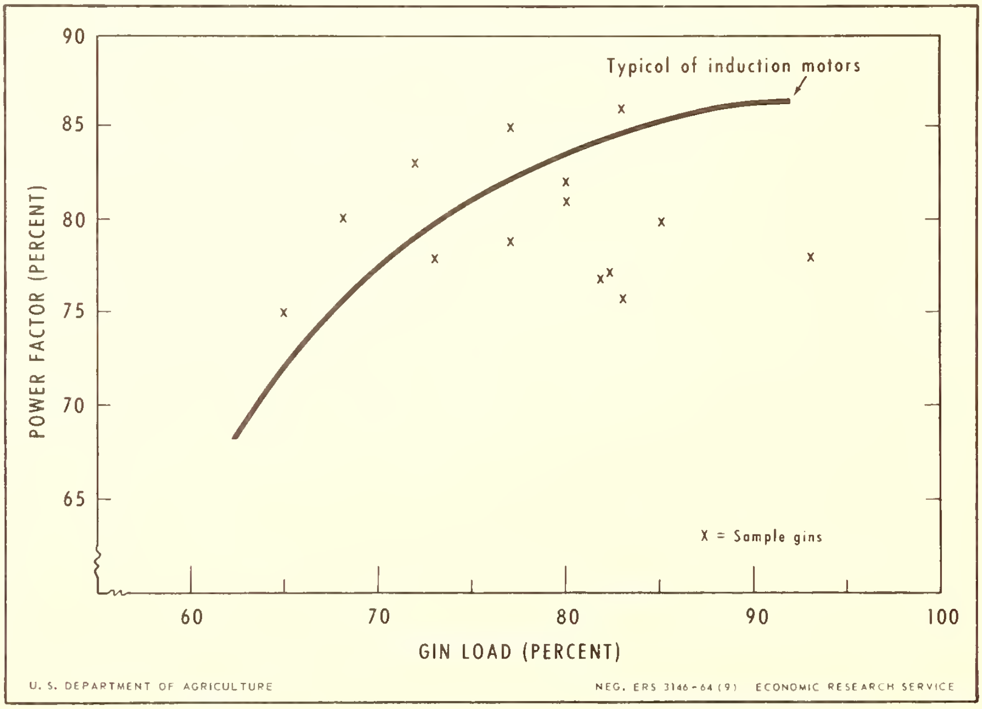

Figure 1.--Relationship of power factor to gin load (ratio of total horsepower required to total connected load), 18 cotton gins, four-State Western Area, 1961-63

determined, or (2) utility company reserves right to adjust actual kw. of demand to basis of _____ percent power factor.

The frequency with which the utility companies used the six types of clauses in their service was as follows:

Number of companies	Type of clause
3	A
21	B
4	C
4	D
5	E
24	F
61	

Type F was most common power factor adjustment clause employed by utility companies specifying power factor adjustment clauses. Approximately 40 percent used some form of this clause, while 35 percent favored Type B. The remainder, whose service contracts contained no power factor adjustment clauses, appeared to be mostly smaller, privately owned utilities. It is assumed that these smaller utility companies provide primarily rural and residential service where power factor levels are of little concern.

MEASURING ACTUAL POWER REQUIREMENTS AND POWER FACTOR LEVELS IN GINS

The actual measurement of individual induction motors and electrical circuits in cotton gins requires no specialized training. Electrical readings can be made by ginners themselves, providing proper equipment is available and specific instructions accompanying each instrument are carefully followed. Once accurate readings have been obtained, determination of power requirements and power factor levels can be made directly from simplified charts which were developed by the authors of this report.

Instruments and Readings Required

Three basic instruments, the voltmeter, ammeter, and either a wattmeter or power factor meter are necessary in determining actual motor loads and power factor levels. Clamp-on meters are recommended because of their ease and simplicity of operation. Two of these instruments, the voltmeter and ammeter, are generally accessible to cotton ginners and when correctly used in combination can give a good indication of the degree to which an induction motor is loaded. Ginners are mainly concerned about overloading induction motors. Electric motors are rated in full-load amperes at a given voltage as well as in horsepower. Thus, voltage and amperage readings for a given motor will usually give a good indication if an overloaded condition exists.

A wattmeter or power factor meter reading is also necessary, however, to make a complete analysis of actual power requirements of separate pieces of equipment and the resulting power-factor levels of individual induction motors. Although not nearly as common to the gin testing equipment inventory as the voltmeter and the ammeter, both the wattmeter and the power factor meter are available on a rental basis at reasonable rates.

Conventional Method of Analyzing Meter Readings-- Using Mathematical Formulas

Engineers rely on the use of rather complicated formulas, mathematical tables, and the slide rule in converting electrical meter readings to meaningful power measurements. Horsepower, the unit of power employed by engineers, is equal to 0.746 kilowatts. Therefore, this measurement is obtained by dividing the wattmeter reading, in kilowatts, by 0.746. That is,

$$\text{Hp. (input)} = \frac{\text{kilowatts (input)}}{0.746}$$

When using a power factor meter instead of a wattmeter, in combination with the voltmeter and ammeter, kilowatts must first be calculated using the following formula:

$$\text{kilowatts (input)} = \sqrt{3} \times \text{kilovolts} \times \text{amperes} \times \text{power factor}$$ [11]

Horsepower output will be slightly less than input due to mechanical inefficiencies incurred in motor operation. Hence, the formula for determining the actual power available from an induction motor or the actual load of a given motor is as follows:

$$\text{Hp. (output)} = \frac{\text{kilowatts (input)} \times \text{motor efficiency}}{0.746}$$

In engineering terms, power factor is the "cosine of the angle theta" and expressed as cos θ. In the absence of a power factor meter, which gives a direct power factor reading, several mathematical formulas are available, the most common being:

$$\text{Power factor} = \frac{\text{kilowatts (input)}}{\sqrt{3} \times \text{kilovolts} \times \text{amperes}}$$ [11]

Simplified Method of Analyzing Meter Readings-- Using Charts

Individuals with limited training in mathematics tend to avoid the use of even simple mathematical formulas and calculations. Consequently, electrical testing equipment, even when available to ginners, often remains unused for lack of ability to convert instrument readings to meaningful power measurements. For this reason, an attempt was made to develop a simple means of directly converting electrical meter readings to the desired power measurements without the use of mathematics. The results are shown in the series of 8 charts which follow (fig. 2-9). The charts differ only in voltage, with the total series covering a range of 430-500 volts in intervals of 10.[12]

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[11] $\sqrt{3}$ must be incorporated in formula in case of 3-wire, 3-phase balanced electrical system of type commonly used in cotton gins.

The following hypothetical example illustrates the simplicity of deriving power measurements, using the chart method as compared to the use of mathematical formulas.

GIVEN:

Power readings - 15 hp. induction motor
Voltage - 430
Kilowatts (input) - 11.5
Amperes - 18.5

TO FIND:

Horsepower (output)
Power factor

CALCULATIONS: Using mathematical formulas

1. Horsepower

$$\text{Hp.} = \frac{\text{kw. (input) x motor efficiency}}{0.746}$$

$$\text{Hp.} = \frac{11.5 \times .85}{0.746} = 13.1$$

2. Power factor

$$\text{P.F.} = \frac{\text{kw. (input)}}{\sqrt{3} \text{ x kilovolts x amperes}}$$

$$\text{P.F.} = \frac{11.5}{1.732 \times 0.430 \times 18.5} = 83.5$$

CALCULATIONS: Using simplified chart (fig. 2)

1. Horsepower

Directly opposite 11.5 kilowatts in the left-hand margin or kilowatt axis read 13.1 in the right hand margin or horsepower axis.

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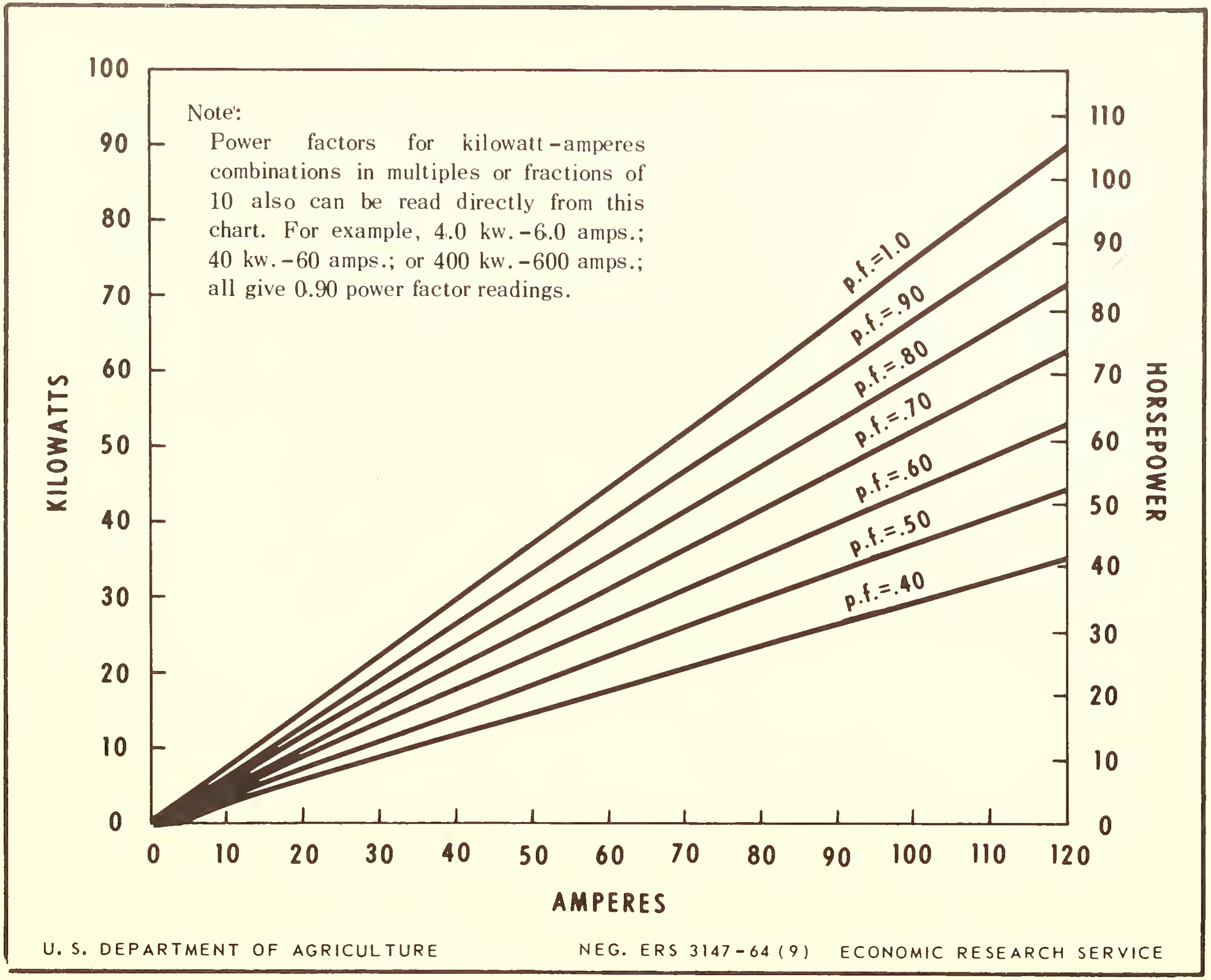
[12] Charts at more frequent voltage intervals can be easily developed, if desired.



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.0 kw.-6.0 amps.; 40 kw.-60 amps.; or 400 kw.-600 amps.; all give 0.90 power factor readings.

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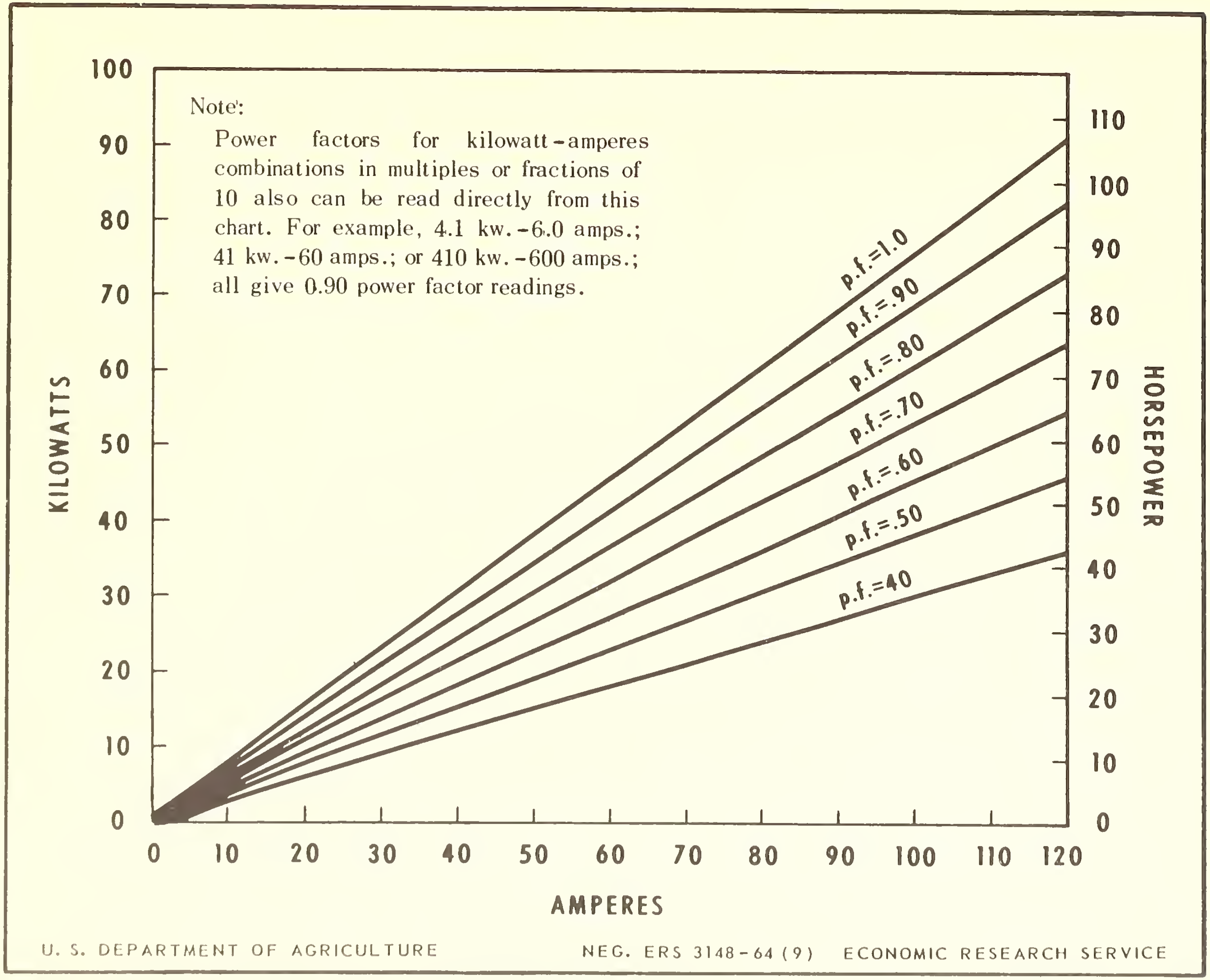
Figure 2.--Relationship of kilowatts to amperes at 430 volts with power factors ranging from 1.0 to 0.40



Note:

Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.1 kw.-6.0 amps.; 41 kw.-60 amps.; or 410 kw.-600 amps.; all give 0.90 power factor readings.

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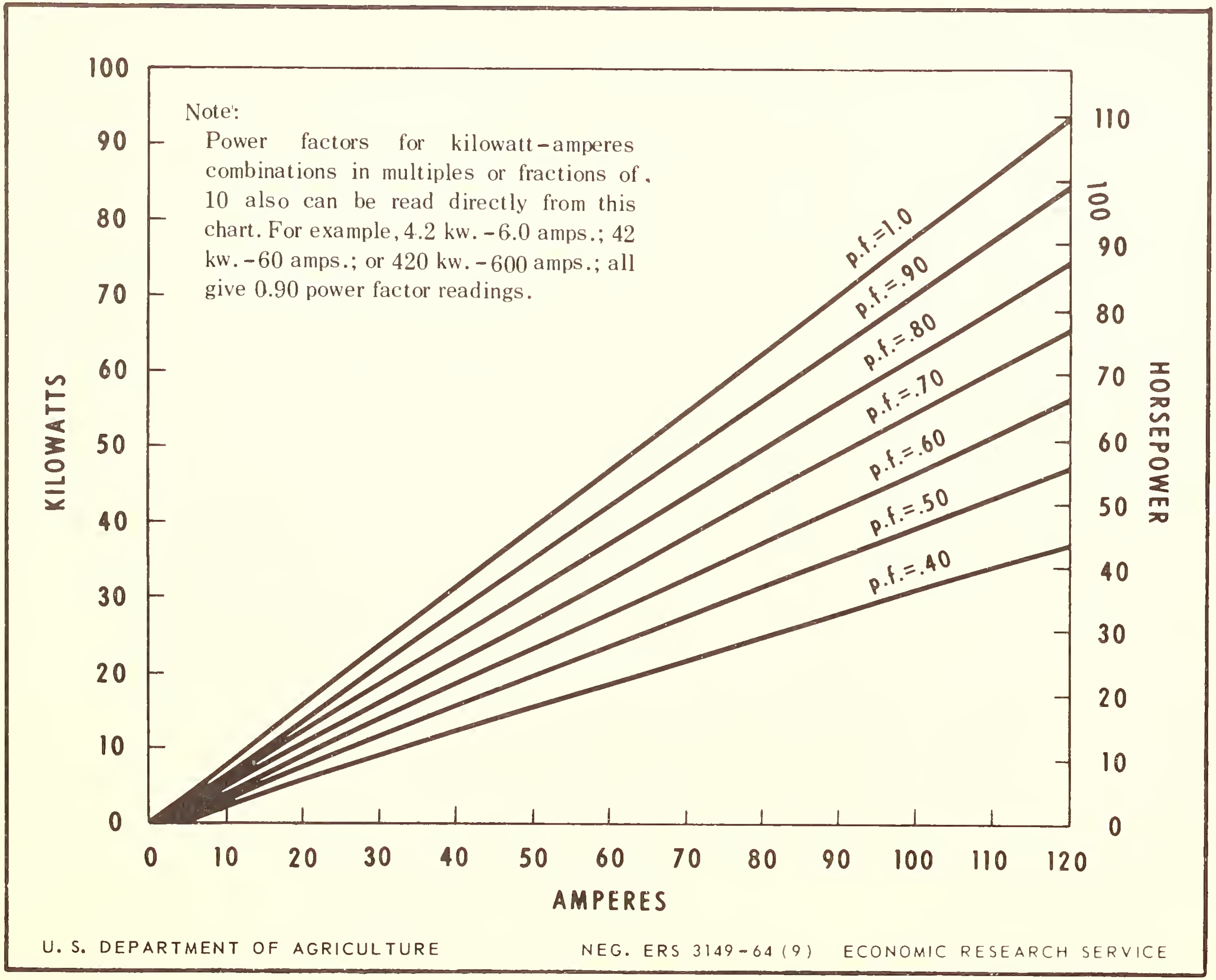
Figure 3.--Relationship of kilowatts to amperes at 440 volts with power factors ranging from 1.0 to 0.40



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.2 kw.-6.0 amps.; 42 kw.-60 amps.; or 420 kw.-600 amps.; all give 0.90 power factor readings.

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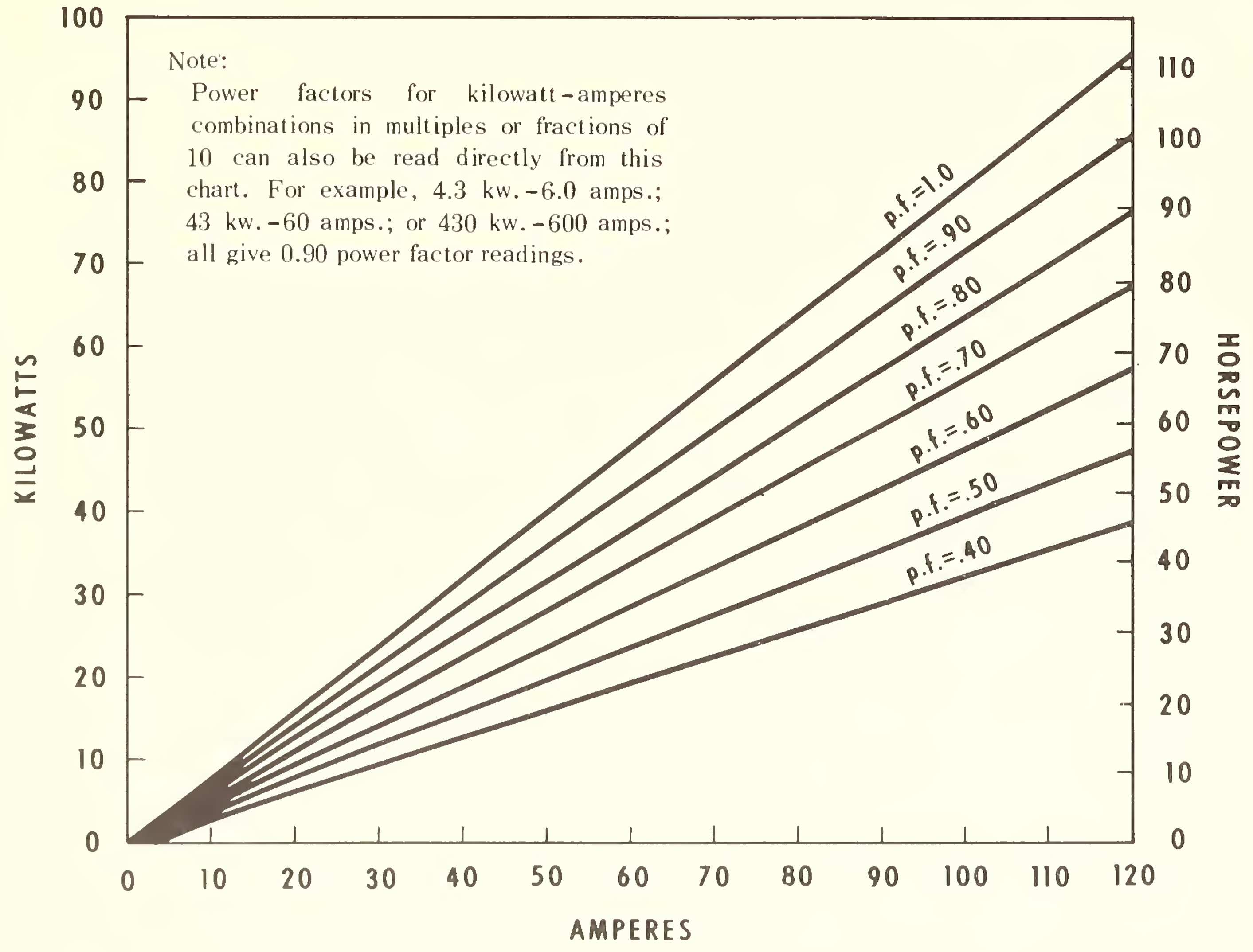
Figure 4.--Relationship of kilowatts to amperes at 450 volts with power factors ranging from 1.0 to 0.40



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 can also be read directly from this chart. For example, 4.3 kw.-6.0 amps.; 43 kw.-60 amps.; or 430 kw.-600 amps.; all give 0.90 power factor readings.

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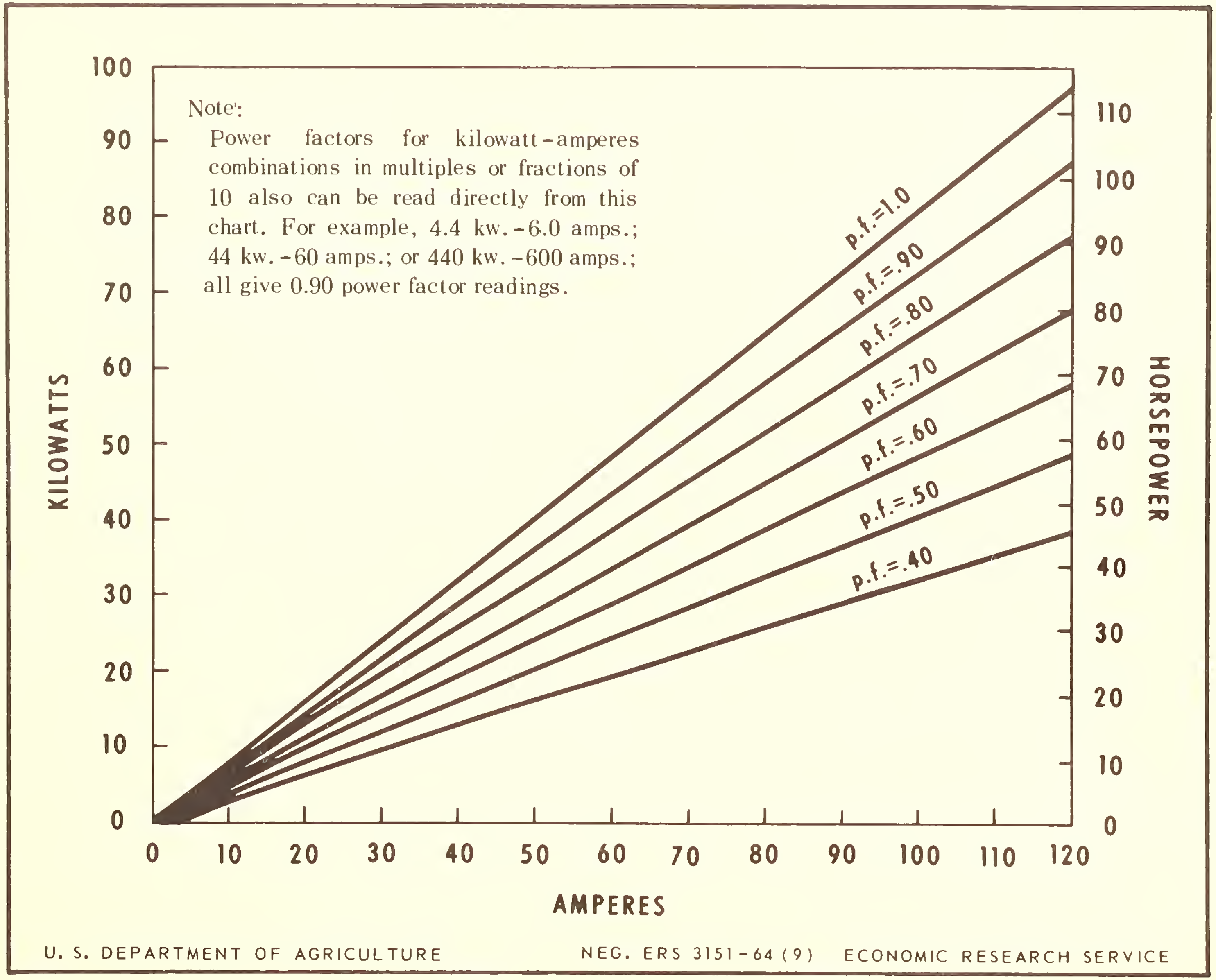
Figure 5.--Relationship of kilowatts to amperes at 460 volts with power factors ranging from 1.0 to 0.40



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.4 kw.-6.0 amps.; 44 kw.-60 amps.; or 440 kw.-600 amps.; all give 0.90 power factor readings.

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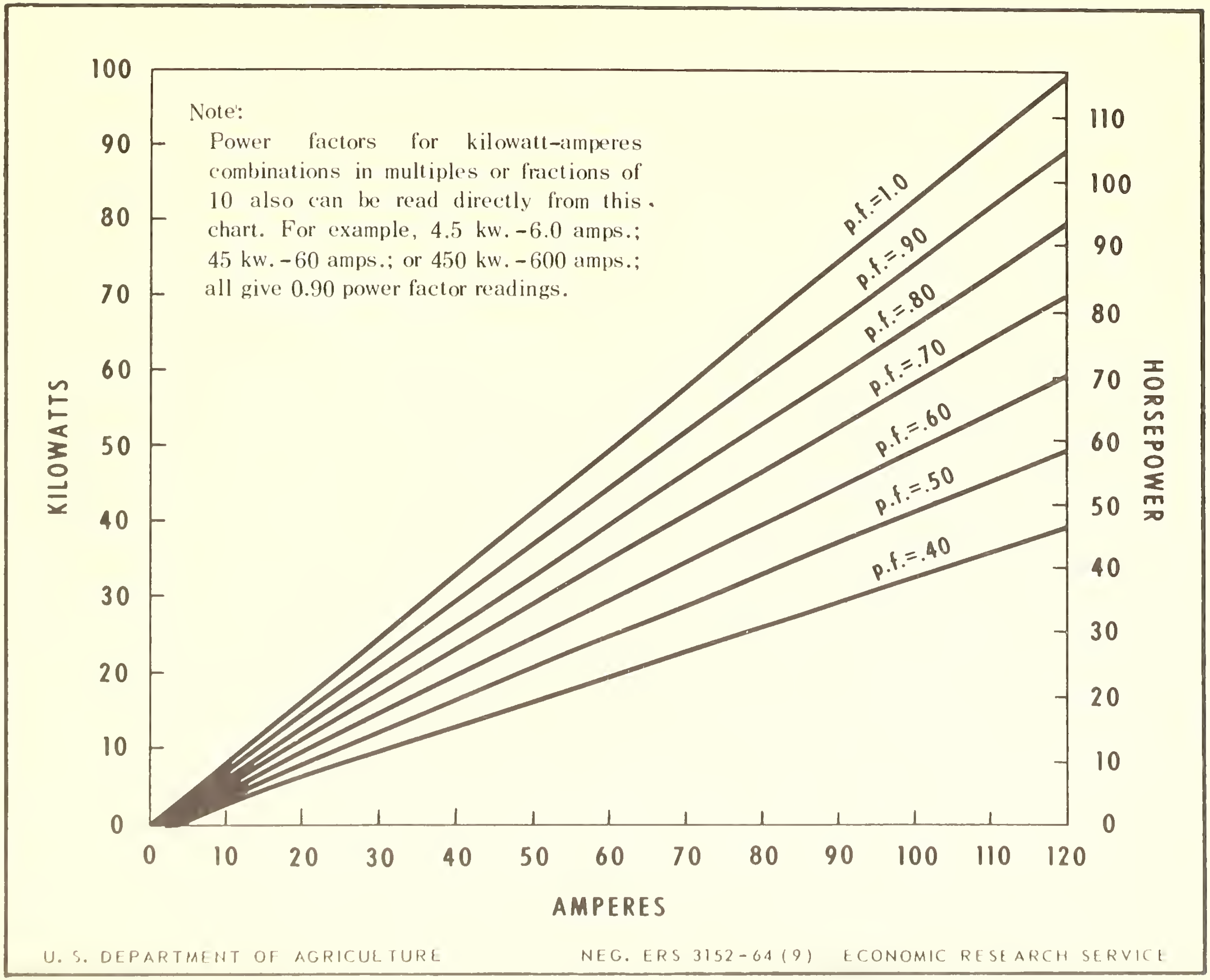
Figure 6.--Relationship of kilowatts to amperes at 470 volts with power factors ranging from 1.0 to 0.40



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.5 kw.-6.0 amps.; 45 kw.-60 amps.; or 450 kw.-600 amps.; all give 0.90 power factor readings.

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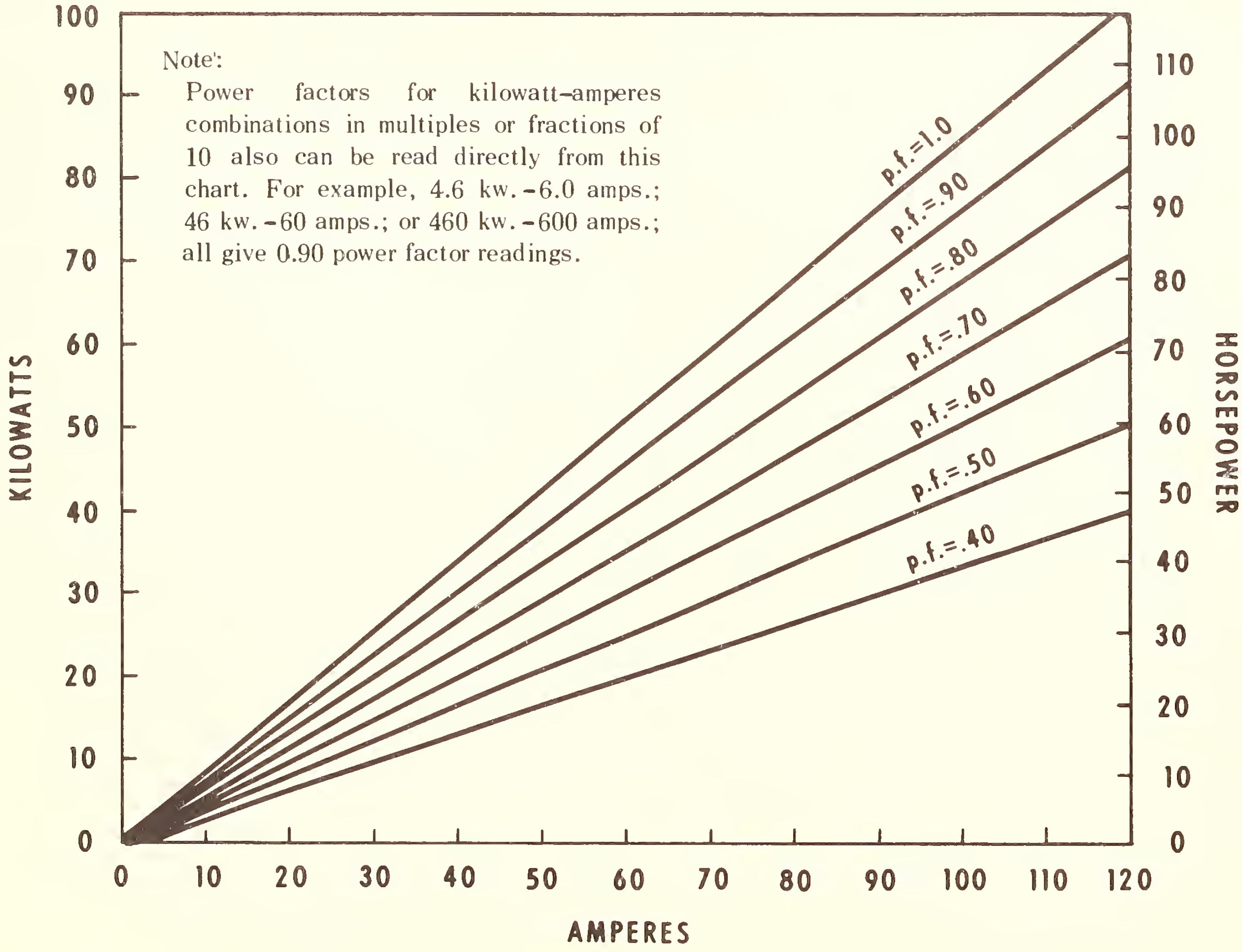
Figure 7.--Relationship of kilowatts to amperes at 480 volts with power factors ranging from 1.0 to 0.40



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.6 kw.-6.0 amps.; 46 kw.-60 amps.; or 460 kw.-600 amps.; all give 0.90 power factor readings.

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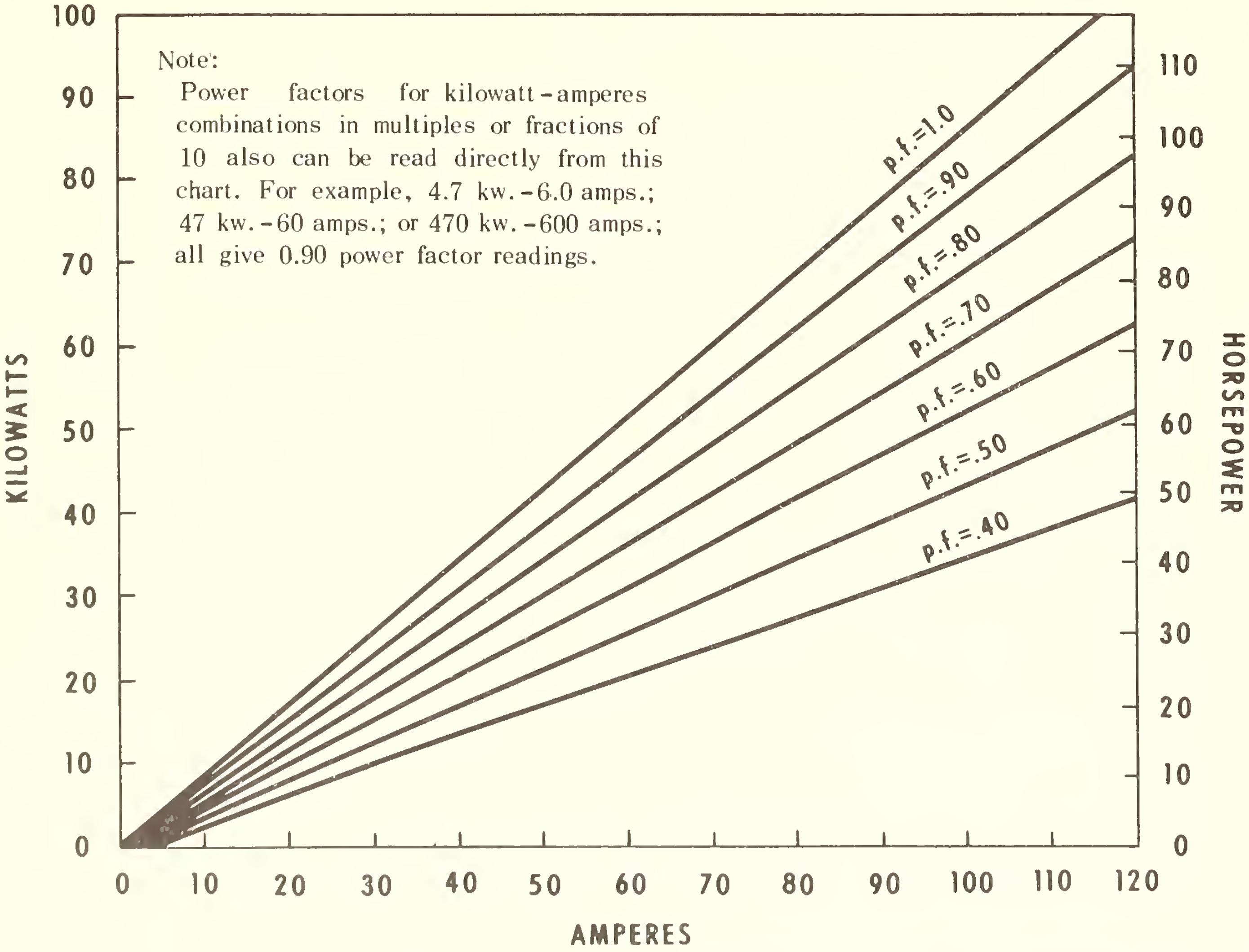
Figure 8.--Relationship of kilowatts to amperes at 490 volts with power factors ranging from 1.0 to 0.40



Note:
Power factors for kilowatt-amperes combinations in multiples or fractions of 10 also can be read directly from this chart. For example, 4.7 kw.-6.0 amps.; 47 kw.-60 amps.; or 470 kw.-600 amps.; all give 0.90 power factor readings.

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Figure 9.--Relationship of kilowatts to amperes to 500 volts with power factors ranging from 1.0 to 0 40

2. Power factor

Draw an imaginary line horizontally from 11.5 kilowatts in the left-hand margin and another vertically from 18.5 amperes in the horizontal axis or amperes axis at the bottom of the chart. Note that the 2 lines intersect at a point in the space between p.f. = .80 and p.f. = .90 about one-third of the distance up from the p.f. = .80 line.

Use of the chart system not only eliminates any mathematical computations, but also acts as an immediate check on measurement discrepancies, should they occur. For instance, assume that readings on a given motor were 440 volts, 42 kilowatts, and 50 amperes. A quick reference to the appropriate chart (fig. 3) indicates that one of these readings must be erroneous, since this combination would provide a power factor reading in excess of 1.0 which is physically impossible. This enables the tester to recheck for reading errors which, otherwise, would have been impossible if the discrepancy had not been detected until later. Frequently, this error can be traced to an unintentional reading from the wrong scale of a multiscale meter.

ECONOMIC CONSIDERATIONS IN CORRECTING OVERMOTORING AND LOW POWER FACTOR LEVELS

The advisability of establishing and maintaining high power factors in cotton gins, from an economic standpoint, depends mainly upon the costs involved and the benefits to be derived. It is obviously of utmost importance to strive for the highest power factors obtainable when making the initial installation of any motor or complement of motors.

Once an installation has been completed, any further attempt to improve power factor levels with corrective devices will result in additional expenses such as expenditures for labor, the outright purchase or exchange of motors, or the purchase of capacitors. Labor costs are governed by many factors and will vary considerably. Currently, a reconditioned motor can be purchased from electrical repair shops and suppliers at costs ranging from one-half to three-fourths of the purchase price of a new unit. It would seem logical, as concern over the problem of overmotoring becomes more widespread, that a motor-exchange pool could be established at considerable savings to ginners.

Capacitors are priced at a fixed cost per unit, thus enabling a fairly close approximation of the cost of an installation, given the required units of capacitance and an estimate of the time and labor required. The formula for determining the required capacitance to raise a power factor from one level to another is: 13/

$$\text{capacitance in kvars} = \text{tangent of original p.f.} - \text{tangent of desired p.f.} \times \text{kilowatts input}$$

For example, it is desired to improve the power factor of a 100-kw. load from 0.68 to 0.95. The tangent of 0.68 is found to be 1.0782, and of 0.95 the

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13/ Capacitors are measured in units (kvars) of capacitance.

tangent is 0.3287. The difference is 0.7495 which rounds to 0.750. This times 100 kw. equals 75 kvars of capacitance required. Calculations of capacitance required for combinations of original power factors ranging from 0.66 to 0.90 and desired power factors ranging from 0.85 to 0.95 per kw. of motor load follow (table 4).

Returns from power factor improvements are both direct and indirect. Power users normally look for the immediate, tangible saving in lowered monthly billings. However, other benefits can and do accrue in the forms of reduced power losses, released system capacity, and improved voltage. In some cases, these less obvious advantages will far exceed those from reduced power costs.

An actual example illustrates how direct savings from power factor improvements can vary depending upon the means used and the nature of the power factor adjustment clause in effect. For this purpose, one of the 18 sample gins was randomly selected. In initiating a power factor correction, a complete motor inventory is first taken along with voltmeter, ammeter, and wattmeter or power factor meter readings on each individual motor. This is essential in determining the best course of action.

In the selected gin plant, approximately two-thirds of all machines were overmotored (table 5). In some cases, overmotoring was extreme. For example, the gin stands were being operated by 40 hp. motors when 30 hp. motors would be the correct size according to the power requirements of each. Likewise, less than one-third of the connected horsepower was actually required to operate the automatic feed. Consequently, there is a wide variation in power factors ranging from a low of 0.41 to a high of 0.91 with an overall level of 0.74 for the plant.

Alternatives Available for Establishing and Maintaining Power Factors at More Desirable Levels

There are 3 basic means of establishing and maintaining more desirable power factor levels. They are (1) properly sizing motors to the jobs to be performed--either during the initial installation, preferably, or later by advancing motors to heavier jobs and replacing smallest with even smaller to secure optimum performance; (2) adding corrective devices to motors already installed--either to further improve the existing power factor level in an already properly sized motor complement or as an alternative means of raising a low power factor level without first resorting to motor size correction; and (3) some combination of the two.

There are no known guides as to the most profitable power factor level to maintain in any given plant. However, levels of 0.90 and 0.95 are both realistic goals and are suggested as alternatives in this case study. The choice between the two will ultimately depend upon their comparative advantages as indicated in net returns.

Within this framework, 6 specific alternatives are proposed for raising the overall power factor level in the selected study gin plant. In addition, to illustrate more vividly the importance of proper motor sizing initially, 3 alternatives, which would have been applicable under this situation, are also discussed and compared.

Table 4.--Kvars of capacitance, per kw. of motor load, required to raise original power factor levels, ranging from 0.66 to 0.90, to desired power factor levels, ranging from 0.85 to 0.95 1/

Original power factor	Desired power factor										
	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95
0.66	.518	.545	.571	.598	.626	.554	.682	.709	.743	.775	.809
0.67	.488	.515	.541	.568	.596	.624	.652	.679	.713	.745	.779
0.68	.459	.486	.512	.539	.567	.595	.623	.650	.684	.716	.750
0.69	.429	.456	.482	.509	.537	.565	.593	.620	.654	.866	.720
0.70	.400	.427	.453	.480	.508	.536	.564	.591	.625	.657	.691
0.71	.372	.399	.425	.452	.480	.508	.536	.563	.597	.629	.663
0.72	.343	.370	.396	.423	.451	.479	.507	.534	.568	.600	.634
0.73	.316	.343	.369	.396	.424	.452	.480	.507	.541	.573	.607
0.74	.289	.316	.342	.369	.397	.425	.453	.480	.514	.546	.580
0.75	.262	.289	.315	.342	.370	.398	.426	.453	.487	.519	.553
0.76	.235	.262	.288	.315	.343	.371	.399	.426	.460	.492	.526
0.77	.209	.236	.262	.289	.317	.345	.373	.400	.434	.466	.500
0.78	.183	.210	.236	.263	.291	.319	.347	.374	.408	.440	.474
0.79	.156	.183	.209	.236	.264	.292	.320	.347	.381	.413	.447
0.80	.130	.157	.183	.210	.238	.266	.294	.321	.355	.387	.421
0.81	.104	.131	.157	.184	.212	.240	.268	.295	.329	.361	.395
0.82	.078	.105	.131	.158	.186	.214	.242	.269	.303	.335	.369
0.83	.052	.079	.105	.132	.160	.188	.216	.243	.277	.309	.343
0.84	.026	.053	.079	.106	.134	.162	.190	.217	.251	.283	.317
0.85	.000	.027	.053	.080	.108	.136	.164	.191	.225	.257	.291
0.86			.026	.053	.081	.109	.137	.167	.198	.230	.265
0.87				.027	.055	.082	.111	.141	.172	.204	.238
0.88					.028	.056	.084	.114	.145	.177	.211
0.89						.028	.056	.086	.117	.149	.183
0.90							.028	.058	.089	.121	.155

1/ Capacitors, used for correcting power factor levels in induction motors, are rated in units of kvars. To determine amount of capacitance required to raise power factor from one level to another, multiply appropriate figure given in table by the kilowatt input.

Table 5.--Case study--selected gin, original motor inventory with power readings taken while ginning, average voltage 440, four-State area study, 1961-62 1/

Equipment operated	Connected hp.	Kilowatts	Amperes	Power factor	Calculated hp.
1. Wad breaker	5	1.5	2.9	.68	1.7
2. Automatic feed	15	3.4	10.9	.41	4.0
3. Big reel drier	15	7.3	17.1	.56	8.5
4. No. 1 stick machine and cleaner	25	11.5	22.5	.67	13.4
5. No. 1 pull and trash fan	75	46.4	68.4	.89	54.1
6. No. 1 push and suction	75	55.4	87.6	.83	64.6
7. No. 2 push	30	19.5	30.5	.84	22.7
8. No. 2 stick and incline	25	11.9	20.3	.77	13.9
9. Airblast and No. 2 pull	75	41.4	64.7	.84	48.3
10. No. 3 incline	30	11.9	28.4	.55	13.9
11. Gin No. 1	40	23.8	47.6	.66	27.8
12. Gin No. 2	40	24.8	52.1	.62	28.9
13. Gin No. 3	40	26.2	53.3	.65	30.5
14. Unit L. C. drive	15	8.1	15.4	.69	9.4
15. Unit L. C. drive	15	7.8	15.1	.68	9.1
16. Unit L. C. drive	15	7.8	15.1	.68	9.1
17. L. C. Hartzelle fan	5	3.0	5.0	.79	3.5
18. L. C. Hartzelle fan	5	3.0	5.0	.79	3.5
19. L. C. Hartzelle fan	5	3.4	5.6	.80	4.0
20. Overflow fan	25	13.7	21.4	.84	16.0
21. L. C. trash mote wheel	40	13.7	27.2	.66	16.0
22. Bulk-type L. C. drive	20	10.7	17.3	.81	12.5
23. Bulk-type L. C. drive	20	10.7	17.3	.81	12.5
24. 36" L. C. exhaust fan	10	8.1	13.3	.80	9.4
25. L. C. mote fan	20	8.8	16.7	.69	10.3
26. Outside trash	2	1.9	3.4	.73	2.2
27. Seed blower	10	8.1	13.5	.79	9.4
28. Seed conveyor	3	2.5	4.2	.78	2.9
29. Outside seed conveyor	2	2.0	3.2	.82	2.3
30. Condenser	3	1.7	3.9	.57	2.0
31. Condenser exhaust fan	10	7.9	11.4	.91	9.2
Total or Average	715	407.9	720.3	.74	475.6

1/ Does not include press, press pump, tramper, and air compressor.

Alternative 1. (Advance motors to heavier jobs and replace the smallest with even smaller to secure optimum performance without resorting to use of corrective devices). This would entail the advancement of 13 motors to new positions, and the replacement of 9 more with motors of different sizes. Those remaining would continue to serve in their original positions. Specific changes to be made are as follows:

Original position (Motor number)	New position (Motor number)	Original position (Motor number)	New position (Motor number)
1	2	17	unchanged
2	8	18	unchanged
3	4	19	unchanged
4	replaced	20	replaced
5	replaced	21	replaced
6	unchanged	22	21
7	11	23	20
8	7	24	unchanged
9	replaced	25	replaced
10	12	26	unchanged
11	replaced	27	unchanged
12	replaced	28	unchanged
13	replaced	29	30
14	10	30	29
15	23	31	unchanged
16	22		

The new motor inventory complete with power readings would appear as in table 6. This shows an appreciable increase in the overall power factor level from 0.74 to 0.87.

Alternative 2. (Advance motors to heavier jobs and replace smallest with even smaller to secure optimum performance. Add capacitance, as necessary, to raise overall power factor level to 0.90). In addition to the changes involved in alternative 1, 33.45 kvars of capacitance would be required to further raise the power factor level from 0.87 to 0.90.[14]

Alternative 3. (Advance motors to heavier jobs and replace smallest with even smaller to secure optimum performance. Add capacitance, as necessary, to raise overall power factor level to 0.95). Changes would be identical to those made in alternative 2 except for the installation of an additional 63.63 kvars of capacitance to further raise the power factor level to 0.95.[15]

Alternative 4. (Raise power factor level to 0.87 with capacitance only). This would accomplish the same results as obtained under alternative 1, but by a different method. The motor inventory would remain unchanged. Instead, the overall power factor would be raised by installing the required amount of capacitance. In this case 139.50 kvars would be necessary.[16]

Alternative 5. (Raise power factor level to 0.90 with capacitance only). Following this alternative, a total of 173.36 kvars of capacitance would be required to raise the original power factor level to 0.90.[17]

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[14] .082 kvars capacitance times 407.9 kilowatts input (table 4).
[15] .238 kvars capacitance times 407.9 kilowatts input (table 4).
[16] .342 kvars capacitance times 407.9 kilowatts input (table 4).
[17] .425 kvars capacitance times 407.9 kilowatts input (table 4).

Alternative 6. (Raise power factor level to 0.95 with capacitance only). In this case, a total of 236.58 kvars of capacitance would need to be installed. 18/

Alternative 7. (Accept resulting overall power factor level without further correction (hypothetical situation--assuming all motors had been correctly sized initially with resulting power factor of 0.87). No change would be necessary and, hence, no cost involved.

Alternative 8. (Add capacitance, as necessary, to raise overall power factor level to 0.90 (hypothetical situation--assuming all motors had been correctly sized initially). Commencing with an overall power factor of 0.87, only 33.45 kvars of capacitance would be required to raise it to 0.90.19/

Alternative 9. (Add capacitance, as necessary, to raise overall power factor level to 0.95 (hypothetical situation--assuming all motors had been correctly sized initially). This would require the installation of 97.08 kvars of capacitance.20/

Costs and Returns Using Various Alternatives

As indicated in table 5, page 23, "type F" and "type B" power factor adjustment clauses were most common among the utility contracts studied. Therefore, two typical power contracts were selected, one incorporating a "type F" adjustment clause and the other a "type B" clause, as bases for computing the anticipated net returns in direct saving from power factor improvements using the various alternatives suggested.

The general level of net profit available from power factor improvement is higher, in this particular case, under the rate schedule with the "type B" power factor adjustment clause (table 7).21/ Of the 3 power factor levels considered, the 0.95 level would be most profitable in each case with alternatives 9, 6, and 3 showing the highest net return, in that order.22/ Net saving as high as $0.11 per bale could be realized.

Perhaps one of the most significant findings to be noted in these cost figures is the net saving of $0.05 to $0.08 per bale, depending upon the power factor adjustment clause, which would have been available immediately if the motors in the case study gin plant had been properly sized when first installed.

18/ .580 kvars capacitance times 407.9 kilowatts input (table 4).

19/ .082 kvars capacitance times 407.9 kilowatts input (table 4).

20/ .238 kvars capacitance times 407.9 kilowatts input (table 4).

21/ This is presumed to be a mere coincidence and is not to infer that the "type B" clause is generally more favorable to gin plant owners than the "type F" or any other power factor clause.

22/ The implication that the highest power factor level obtainable would be the most profitable to maintain, could be misleading. It must be remembered that all cost figures were estimated and that any substantial deviations from these estimates, which might be experienced in actuality, could alter these relative positions substantially.

Table 6.--Case study--selected gin, motor inventory with power readings taken while ginning, following alternative 1 modification (13 motors relocated, 9 motors replaced), average voltage 460, four-State area study, 1961-62 1/

Equipment operated	Connected hp.	Kilowatts	Amperes	Power factor	Calculated hp.
1. Wad breaker	2	1.5	2.3	.82	1.7
2. Automatic feed	5	3.4	5.1	.84	4.0
3. Big reel drier	10	7.3	10.4	.88	8.5
4. No. 1 stick machine and cleaner	15	11.5	16.4	.88	13.4
5. No. 1 pull and trash fan	60	46.4	64.7	.90	54.1
6. No. 1 push and suction	75	55.4	85.8	.81	64.6
7. No. 2 push	25	19.5	27.2	.90	22.7
8. No. 2 stick and incline	15	11.9	16.4	.91	13.9
9. Airblast and No. 2 pull	50	41.4	57.7	.90	48.3
10. No. 3 incline	15	11.9	16.4	.91	13.9
11. Gin No. 1	30	23.8	33.2	.90	27.8
12. Gin No. 2	30	24.8	35.0	.89	28.9
13. Gin No. 3	30	26.2	36.5	.90	30.5
14. Unit L. C. drive	10	8.1	11.6	.88	9.4
15. Unit L. C. drive	10	7.8	11.3	.87	9.1
16. Unit L. C. drive	10	7.8	11.3	.87	9.1
17. L. C. Hartzelle fan	5	3.0	4.8	.79	3.5
18. L. C. Hartzelle fan	5	3.0	4.8	.79	3.5
19. L. C. Hartzelle fan	5	3.4	5.3	.80	4.0
20. Overflow fan	20	13.7	18.9	.91	16.0
21. L. C. trash mote wheel	20	13.7	18.9	.91	16.0
22. Bulk-type L. C. drive	15	10.7	14.8	.91	12.5
23. Bulk-type L. C. drive	15	10.7	14.8	.91	12.5
24. 36" L. C. exhaust fan	10	8.1	12.7	.80	9.4
25. L. C. mote fan	10	8.8	12.6	.88	10.3
26. Outside trash	2	1.9	2.8	.85	2.2
27. Seed blower	10	8.1	12.9	.79	9.4
28. Seed conveyor	3	2.5	4.0	.78	2.9
29. Outside seed conveyor	3	2.0	3.1	.81	2.3
30. Condenser	2	1.7	2.6	.82	2.0
31. Condenser exhaust fan	10	7.9	10.9	.91	9.2
Total or Average	527	407.9	585.2	.87	475.6

1/ Does not include press, press pump, tramper, and air compressor.

Although much more difficult to estimate, additional benefits in indirect saving can also accrue from improved power factor levels. For example, an increase in the power factor level will result in a corresponding increase in the voltage level. This is particularly important in the case of excessively low or fluctuating voltages which tend to cause sluggishness and overheating in electric motors.

Table 7.--Cost and direct saving from raising power factors to designated levels by various alternative means under two different "types" of power factor adjustment clauses, case study--selected gin, four-State area study, 1961-62 1/

Items	Alternatives 2/								
	1	2	3	4	5	6	7	8	9
Original power factor...	0.74	0.74	0.74	0.74	0.74	0.74	3/	3/	3/
New power factor........	0.87	0.90	0.95	0.87	0.90	0.95	0.87	0.90	0.95
Total cost (dollars) 4/.	1332.00	1604.00	2098.00	1155.00	1404.00	1896.00	---	372.00	866.00
Annual cost (dollars) 5/	66.60	80.20	104.90	57.75	70.20	94.80	---	18.60	43.30
					"type F" 6/				
Annual gross saving (dollars)............	306.30	374.85	487.13	306.30	374.85	487.13	306.30	374.85	487.13
Annual net saving:									
Total (dollars).......	239.70	294.65	382.23	248.55	304.65	392.33	306.30	356.25	443.83
Per bale (dollars) 7/.	0.04	0.05	0.06	0.04	0.05	0.07	0.05	0.06	0.07
					"type B" 8/				
Annual gross saving (dollars)............	490.38	523.51	702.19	490.38	523.51	702.19	490.38	523.51	702.19
Annual net saving:									
Total (dollars).......	423.78	443.31	597.29	432.63	453.31	607.39	490.38	504.91	658.89
Per bale (dollars) 7/.	0.07	0.07	0.10	0.07	0.08	0.10	0.08	0.08	0.11

1/ Direct saving includes saving in billing charges and reduction in power losses only.

2/ Alternative 1 - Advance, substitute, and replace motors for optimum performance without corrective devices.

Alternative 2 - Advance, substitute, and replace motors for optimum performance. Add capacitance, as necessary, to raise overall power factor level to 0.90.

Alternative 3 - Advance, substitute, and replace motors for optimum performance. Add capacitance, as necessary, to raise overall power factor level to 0.95.

Alternative 4 - Raise power factor level to 0.87 with capacitance only.

Alternative 5 - Raise power factor level to 0.90 with capacitance only.

Alternative 6 - Raise power factor level to 0.95 with capacitance only.

Alternative 7 - Accept resulting overall power factor level without further correction (hypothetical case--assumed that all motors were correctly sized in initial installation).

Alternative 8 - Add capacitance, as necessary, to raise overall power factor level to 0.90 (hypothetical case--assumed that all motors were correctly sized in initial installation).

Alternative 9 - Add capacitance, as necessary, to raise overall power factor level to 0.95 (hypothetical case--assumed that all motors were correctly sized in initial installation).

3/ Based on original power factor level of 0.74 in selected gin for comparative analysis with alternatives 1 through 6.

4/ Alternative 1 - Cost of new motor ($2,982) minus allowance for trade-in ($1,900) plus labor ($250).
Alternative 2 - Net exchange on motors ($1,082), 33.45 kvars of capacitance ($247), and labor ($275).
Alternative 3 - Net exchange on motors ($1,082), 63.63 kvars of capacitance ($716), and labor ($300).
Alternative 4 - Cost of 139.50 kvars of capacitance ($1,030) and labor ($125).
Alternative 5 - Cost of 173.36 kvars of capacitance ($1.279) and labor ($125).
Alternative 6 - Cost of 236.58 kvars of capacitance ($1,746) and labor ($150).
Alternative 8 - Cost of 33.45 kvars of capacitance ($247) and labor ($125).
Alternative 9 - Cost of 97.08 kvars of capacitance ($716) and labor ($150).

5/ Based on 20-year depreciation schedule.

6/ "Type F"--. . . demand charge will be decreased or increased by ___cents per kw. for each 1 percent the average power factor is above or below 80 percent, lagging to a maximum discount of ___ cents per kw. demand.

7/ Based on an annual volume of 6,000 bales.

8/ "Type B"--When power factor . . . is less than 85 percent, or more than 90 percent, the billing demand will be adjusted by multiplying the monthly maximum measured demand by 85 percent, or 90 percent, and dividing the product by the power factor determined.

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C. 20250

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Deterioration of insulation from overheating could shorten wiring life expectancy by as much as 25 percent or more. This would amount to an additional loss of $300 - $400 annually, assuming a normal depreciation in gin wiring, motors, and other electrical components of $1,000 per year.

An increase in voltage will also release system capacity by reducing the amperage required. This is a particularly important item when the installation of additional ginning equipment is being considered. If machinery can be added without supplementing or reinforcing existing electrical circuits, this can mean a saving oftentimes equal to, or greater than, the total cost of the power factor improvement.